Claims

WHAT IS CLAIMED IS:

1. An inert gas generating system for generating inert gas on a vehicle having a fuel tank and a fuel tank vent, said system comprising:

an inlet for receiving a flow of gas having a nitrogen component and an oxygen component from a gas source;

a heat exchanger downstream from the inlet and in fluid communication with the inlet for cooling gas received from the inlet; and

a gas separation module downstream from the heat exchanger and in fluid communication with the heat exchanger for separating gas received from the heat exchanger into a nitrogen-enriched gas flow and an oxygen-enriched gas flow, said gas separation module being adapted to deliver nitrogen-enriched gas from the nitrogen-enriched gas flow to the fuel tank without delivering the nitrogen-enriched gas through the fuel tank vent, said gas separation module being adapted to deliver nitrogen-enriched gas from the nitrogen-enriched gas flow to the fuel tank vent.

2. A system in accordance with claim 1 further comprising a flow valve operatively connected downstream from the gas separation module to control a flow rate of the nitrogen-enriched gas flow received from the gas separation module.

3. A system in accordance with claim 1 in combination with a fuel tank valve operatively connected between the gas separation module and the fuel tank to control a flow rate of nitrogen-enriched gas into the fuel tank.

4. A system in accordance with claim 1 in combination with a fuel tank vent valve operatively connected between the gas separation module and the fuel tank vent to control a flow rate of nitrogen-enriched gas into the fuel tank vent.

5. A system in accordance with claim 1 further comprising a flow sensor operatively connected downstream from the gas separation module to measure

at least one of a flow rate and a pressure of the nitrogen-enriched gas flow downstream from the gas separation module.

6. A system in accordance with claim 1 further comprising an oxygen sensor operatively connected downstream from the gas separation module to measure an oxygen content of the nitrogen-enriched gas flow downstream from the gas separation module.

7. A system in accordance with claim 1 further comprising a compressor operatively connected between the inlet and the heat exchanger to increase a pressure of the gas received by the heat exchanger.

8. A system in accordance with claim 7 wherein operation of the compressor is driven by gas received from the inlet.

9. A system in accordance with claim 7 further comprising:

a pressure sensor operatively connected downstream from the compressor to measure a pressure of gas downstream from the compressor; and

a compressor regulator valve operatively connected to the compressor and the pressure sensor for controlling operation of the compressor based on the pressure of the gas downstream from the compressor.

10. A system in accordance with claim 9 further comprising a processor operatively connected between the pressure sensor and the compressor regulator valve for controlling operation of the compressor regulator valve based on the pressure of the gas downstream from the compressor.

11. A system in accordance with claim 7 further comprising a compressor bypass check valve operatively connected between the inlet and the heat exchanger to allow gas to bypass the compressor.

12. A system in accordance with claim 1 further comprising:

a temperature sensor operatively connected downstream from the heat exchanger to measure a temperature of gas downstream from the heat exchanger; and

a heat exchanger bypass valve operatively connected between the inlet and the gas separation module to allow gas to bypass the heat exchanger, said heat exchanger bypass valve operatively connected to the temperature sensor for controlling the temperature of the gas received by the gas separation module based on the temperature of the gas downstream from the heat exchanger.

13. A system in accordance with claim 12 further comprising a processor operatively connected between the temperature sensor and the heat exchanger bypass valve for controlling operation of the heat exchanger bypass valve based on the temperature of the gas downstream from the heat exchanger.

14. A system in accordance with claim 1 further comprising a ground connection port operatively connected between the heat exchanger and the gas separation module for introducing air to the gas separation module from a pre-conditioned air source external to the vehicle.

15. A system in accordance with claim 1 further comprising a filter operatively connected between the heat exchanger and the gas separation module to filter at least one of entrained moisture and particulate contaminants from gas flowing between the heat exchanger and the gas separation module.

16. A system in accordance with claim 1 wherein the gas separation module comprises a permeable membrane gas separation module.

17. A system in accordance with claim 1 further comprising a ground connection port operatively connected downstream from the gas separation module for introducing nitrogen-enriched gas from a nitrogen-enriched gas source external to the aircraft to at least one of the fuel tank and the fuel tank vent, and to allow withdrawal of nitrogen-enriched gas from the nitrogen-enriched gas flow generated by the gas separation module.

18. An aircraft comprising:

an airframe;

a fuel tank mounted on the airframe;

a fuel tank vent operatively connected to the fuel tank; and

an inert gas generating system for generating inert gas on-board the aircraft, said inert gas generating system comprising:

an inlet for receiving a flow of air from an air source;

a heat exchanger downstream from the inlet and in fluid communication with the inlet for cooling air received from the inlet; and

a gas separation module downstream from the heat exchanger and in fluid communication with the heat exchanger for separating air received from the heat exchanger into a nitrogen-enriched gas flow and an oxygen-enriched gas flow, said gas separation module being adapted to deliver nitrogen-enriched gas from the nitrogen-enriched gas flow to the fuel tank without delivering the nitrogen-enriched gas through the fuel tank vent, said gas separation module being adapted to deliver nitrogen-enriched gas from the nitrogen-enriched gas flow to the fuel tank vent.

19. An aircraft in accordance with claim 18 wherein said inert gas generating system further comprises a ground connection port operatively connected between the heat exchanger and the gas separation module for introducing gas to the gas separation module from a pre-conditioned gas source external to the aircraft.

20. An aircraft in accordance with claim 18 wherein said inert gas generating system further comprises a ground connection port operatively connected downstream from the gas separation module for introducing nitrogen-enriched gas from a nitrogen-enriched gas source external to the aircraft to at least one of the fuel tank and the fuel tank vent, and to allow withdrawal of nitrogen-enriched gas from the nitrogen-enriched gas flow generated by the gas separation module.

21. An aircraft in accordance with claim 18 further comprising a gas turbine engine for propelling the aircraft and an environmental control system for

conditioning bleed air from the engine, wherein the air source includes at least one of the gas turbine engine and the environmental control system.

22. A method of generating inert gas on a vehicle for supplying the inert gas to a fuel tank, said method comprising:

supplying a flow of gas having a nitrogen component and an oxygen component to a gas separating module;

separating the flow of gas into a nitrogen-enriched gas flow and an oxygen-enriched gas flow using the gas separating module, wherein the nitrogen-enriched gas flow has an oxygen concentration low enough that the nitrogen-enriched gas flow is generally inert; and

delivering the nitrogen-enriched gas flow from the gas separating module to the fuel tank at a multiplicity of unique flow rates, each unique flow rate of said multiplicity of flow rates corresponding to a different operating condition of the aircraft.

23. A method in accordance with claim 22 wherein said nitrogen-enriched gas flow is delivered to the fuel tank at a pre-determined flow rate generally sufficient to ensure the gas above the fuel in the tank is incombustible when the vehicle is on the ground and when the vehicle is climbing.

24. A method in accordance with claim 23 wherein the fuel tank includes a fuel tank vent and said nitrogen-enriched gas flow is delivered to the fuel tank without passing through the fuel tank vent.

25. A method in accordance with claim 22 wherein said nitrogen-enriched gas flow is delivered to the fuel tank at a pre-determined flow rate generally sufficient to ensure the gas above the fuel in the tank is incombustible when the vehicle is cruising at a generally constant altitude.

26. A method in accordance with claim 25 wherein said nitrogen-enriched gas flow delivered to the fuel tank is restricted to the predetermined flow rate using at least a flow valve.

27. A method in accordance with claim 25 wherein the fuel tank includes a fuel tank vent and said nitrogen-enriched gas flow is delivered to the fuel tank through the fuel tank vent.

28. A method in accordance with claim 22 wherein said nitrogen-enriched gas flow is delivered to the fuel tank at a pre-determined flow rate generally sufficient to ensure the gas above the fuel in the tank is incombustible when the vehicle is descending.

29. A method in accordance with claim 28 wherein the fuel tank includes a fuel tank vent and said nitrogen-enriched gas flow is delivered to the fuel tank through the fuel tank vent.

30. A method in accordance with claim 28 wherein the fuel tank includes a fuel tank vent and said nitrogen-enriched gas flow is delivered to the fuel tank without passing through the fuel tank vent and said nitrogen-enriched gas flow is delivered to the fuel tank through the fuel tank vent when the vehicle is descending faster than a predetermined descent rate.

31. A method in accordance with claim 22 wherein said supplying the gas to the gas separating module comprises supplying the gas at a unique temperature for each unique flow rate of the nitrogen-enriched gas flow.

32. A method in accordance with claim 22 wherein the fuel tank includes a fuel tank vent, said method further comprising warming the gas separating module by delivering a first portion of said nitrogen-enriched gas flow to the fuel tank through the fuel tank vent and delivering a second portion of said nitrogen-enriched gas flow to the fuel tank without delivering the second portion through the fuel tank vent.

33. A method in accordance with claim 22 further comprising compressing the gas before supplying the gas to the gas separating module.

34. A method in accordance with claim 22 further comprising cooling the gas before supplying the gas to the gas separating module.

35. A method in accordance with claim 22 further comprising filtering at least one of entrained moisture and particulate contaminants from the gas before supplying the gas to the gas separating module.

36. A method in accordance with claim 22 further comprising, when the vehicle is cruising at a generally constant altitude, delivering said nitrogen-enriched gas flow to the fuel tank at a pre-determined flow rate generally sufficient to ensure the gas above the fuel in the tank is incombustible when the vehicle is on the ground and when the vehicle is climbing.

37. A method in accordance with claim 36 wherein said nitrogen-enriched gas flow is delivered to the fuel tank without passing through the fuel tank vent.

38. A method in accordance with claim 22 further comprising displaying a time required for the fuel tank to become generally incombustible.

39. A method in accordance with claim 22 further comprising displaying a maximum rate at which the vehicle can descend while the tank is incombustible.

40. A method of generating inert gas on a vehicle for supplying the inert gas to a fuel tank having a fuel tank vent, said method comprising:

supplying a flow of gas having a nitrogen component and an oxygen component to a gas separating module;

separating the flow of gas into a nitrogen-enriched gas flow and an oxygen-enriched gas flow using the gas separating module, wherein the nitrogen-enriched gas flow has an oxygen concentration low enough that the nitrogen-enriched gas flow is generally inert;

delivering nitrogen-enriched gas from the nitrogen-enriched gas flow to the fuel tank without delivering the nitrogen-enriched gas through the fuel tank vent; and

delivering nitrogen-enriched gas from the nitrogen-enriched gas flow to the fuel tank vent.

41. A method in accordance with claim 40 further comprising displaying a time required for the fuel tank to become generally incombustible.

42. A method in accordance with claim 40 further comprising displaying a maximum rate at which the vehicle can descend while the tank is incombustible.

43. A method of generating inert gas on a vehicle for supplying the inert gas to a fuel tank, said method comprising:

supplying a flow of gas having a nitrogen component and an oxygen component to a gas separating module;

separating the flow of gas into a nitrogen-enriched gas flow and an oxygen-enriched gas flow using the gas separating module, wherein the nitrogen-enriched gas flow has an oxygen concentration low enough that the nitrogen-enriched gas flow is generally inert; and

delivering the nitrogen-enriched gas flow from the gas separating module to the fuel tank at a plurality of unique flow rates, wherein the flow of gas supplied to the gas separating module has a unique temperature for each unique flow rate of said plurality of unique flow rates.

44. A method in accordance with claim 43 further comprising displaying a time required for the fuel tank to become generally incombustible.

45. A method in accordance with claim 43 further comprising displaying a maximum rate at which the vehicle can descend while the tank is incombustible.

46. An inert gas generating system for generating inert gas on a vehicle having a fuel tank, said system comprising:

an inlet for receiving a flow of gas having a nitrogen component and an oxygen component from a gas source;

a heat exchanger downstream from the inlet and in fluid communication with the inlet for cooling gas received from the inlet; and

a gas separation module downstream from the heat exchanger and in fluid communication with the heat exchanger for separating gas received from the heat exchanger into a nitrogen-enriched gas flow and an oxygen-enriched gas flow, said gas separation module being adapted to generate a flow rate of the nitrogen-enriched gas flow of about 40 pounds per minute with an oxygen content less than or equal to about 9.8 percent by volume.